14.—The petrology of the Mt Gardner Adamellite, near Albany, Western Australia

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Abstract.

The Mt Gardner Adamellite is emplaced in Precambrian amphibolite facies gneisses of the Albany-Esperance Block, about 30 km east of Albany, Western Australia. It is a composite pluton composed mainly of coarse-grained, porphyritic adamellite intruded by dykes of microadamellite and by very minor pegmatite and quartz veins. Field evidence strongly suggests that the pluton was intrusively emplaced as a magma or crystal mush. Chemical data are consistent with derivation of the microadamellite dykes from the porphyritic adamellite magma by concentration of residual liquids, perhaps by filter pressing, during the later stages of crystallisation. The pegmatite and quartz veins are possibly the products of more advanced fractionation. The magma probably originated by anatexis of crustal rock below the present level of emplacement of the pluton during the orogeny responsible for regional metamorphism of the country rocks.

Introduction

Mt Gardner Adamellite is the name proposed for a granitic pluton situated at the southern end of Two People Bay on the south coast of Western Australia, about 30 km east of Albany (Figure 1). It is named after Mt Gardner, a prominent topographic expression of the pluton, located at 35° 00'S latitude and 118° 10'E longitude. The Mt Gardner Adamellite is one of a number of granitic plutons emplaced in the Precambrian high-grade metamorphic rocks of the Albany-Esperance Block, and has not been described previously. The purpose of this paper is to discuss the origin of this pluton in the light of new field, petrographic, and chemical data. A geological map is attached (Figure 2).

The chemical and modal analytical methods used in this study have been summarised elsewhere (Stephenson 1973). Mesonorms were calculated using the method of Barth (1962), and plagioclase compositions were estimated from measurements of the extinction angle X' ∧ 010 in sections perpendicular to x (Deer *et al.* 1963, Fig. 55). Sample numbers refer to the collection of the Geology Department, University of Western Australia.

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Country Rocks

Introduction

The basement rocks of the south coast part of the Albany-Esperance Block are Precambrian

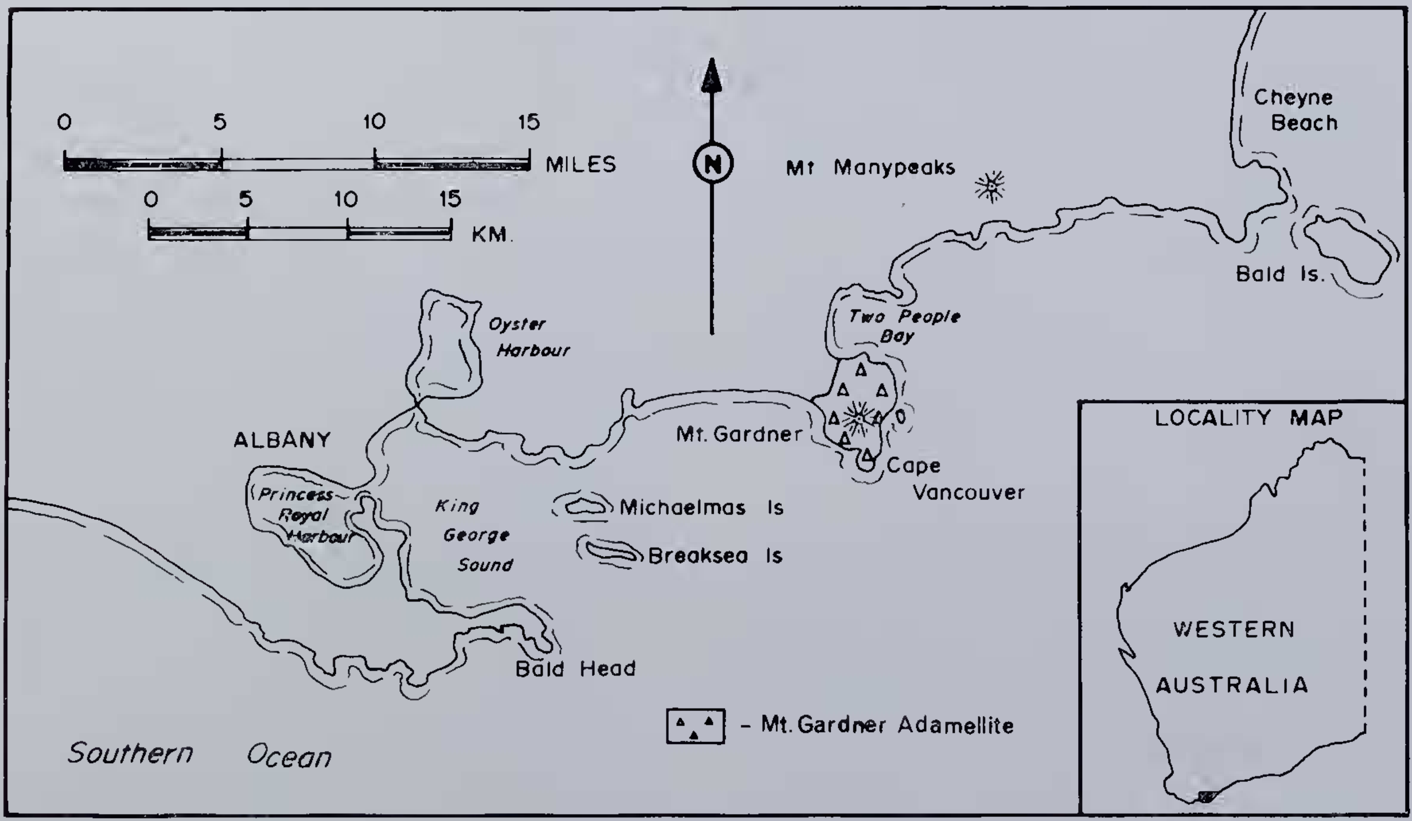

Figure 1.—Map of the Albany district showing the location of the Mt Gardner Adamellite.

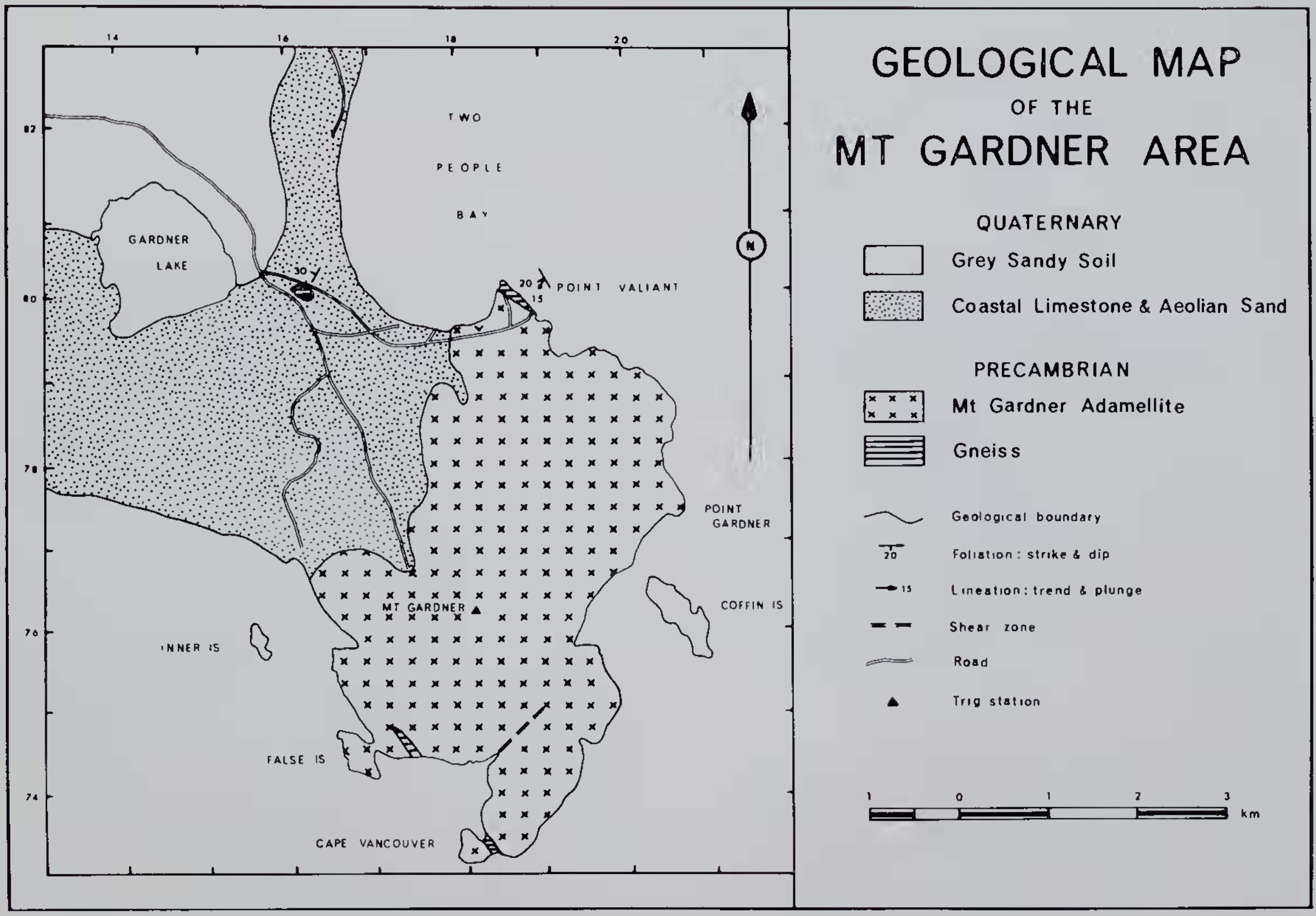

Figure 2.—Geological map of the Mt Gardner area.

gneisses with roughly east-west tectonic trends. These gneisses are predominantly granitic in composition, with intercalated metasedimentary and metabasite bands. Migmatites are common. The metamorphic grade varies from upper amphibolite to lower granulite facies. Granulite facies rocks from the Fraser Range, at the northeastern end of the Albany-Esperance Block, gave a Rb-Sr age of 1330±15 m.y. (Compston and Arriens 1968) and this could be the age of the main metamorphism throughout the block.

The gneissic country rocks surrounding the Mt Gardner Adamellite have been largely obscured by Recent unconsolidated dune sands and by the Southern Ocean. However, they appear to be largely granitic in character, with occasional thin dioritic bands and lenses.

Petrography

1. The *granitic gneiss* is poorly foliated, equigranular fine- to medium-grained, and highly leucocratic. Quartz, oligoclase, and microcline in sub-equal amounts are the major constituents. Biotite is the main accessory and a few samples contain a little green hornblende. Minor accessories include magnetite, sphene, epidote, muscovite, apatite, allanite, and zircon. The texture is predominantly granoblastic, commonly modified by the occurrence of biotite either in small streaky aggregates or in well oriented disseminated flakes. In some samples, especially those collected close to the margin of the Mt Gardner Adamellite, microcline tends to corrode and enclose other minerals, suggesting metasomatic growth. Chemical analyses and modes of four representative samples are presented in Table 1.

2. The *dioritic gneiss* is a fine- to medium-grained, equigranular, dark grey, mesocratic rock composed mainly of andesine, green hornblende, biotite, and quartz. Microcline is locally present. Minor accessories include magnetite, sphene, apatite, allanite, and zircon. The texture is usually weakly foliated due to the preferred orientation of hornblende and biotite. The chemical analysis and mode of a representative sample is presented in Table 1.

Metamorphic facies

The mineral assemblages most common in the gneisses around the Mt Gardner Adamellite may be summarised as follows:

1. Granitic gneiss—
   Quartz-plagioclase-microcline-biotite± hornblende.
2. Dioritic geneiss—
   Quartz-plagioclase-biotite-hornblende± microcline.

These assemblages are characteristic of the amphibolite metamorphic facies (Turner 1968).

Table 1

Chemical analyses and modes of granitic and dioritic gneisses from Mt Gardner

	Granitic gneiss				Dioritic gneiss
	56578	56585	56592	56593	54513
SiO_2	72·26	76·12	77·51	76·15	56·20
Al_2O_3	12·93	12·21	11·83	12·82	14·98
Fe_2O_3	2·59	1·22	0·47	1·00	2·35
FeO	1·53	1·00	0·70	1·01	5·47
MgO	0·52	0·23	0·13	0·42	5·19
CaO	2·03	1·21	0·54	1·30	6·68
Na_2O	3·57	3·19	3·25	3·38	3·00
K_2O	3·24	4·30	5·22	4·17	3·29
H_2O^+	0·36	0·21	0·33	0·22	0·99
H_2O^-	0·11	0·13	0·10	0·16	0·14
TiO_2	0·34	0·16	0·06	0·15	1·29
P_2O_5	0·09	0·02	0·01	0·04	0·69
MnO	0·06	0·05	0·02	0·03	0·15
Total	99·63	100·05	100·17	100·85	100·42
Trace Elements (p.p.m.)					
Li	16	10	22	10	18
Co	4	<3	3	3	32
Ni	26	20	19	24	87
Cu	6	5	4	4	49
Zn	78	54	44	51	101
Rb	137	172	267	143	177
Sr	240	101	22	108	593
Y	36	42	134	35	42
Zr	259	138	97	154	303
Ba	1501	1141	277	1696	1667
La	67	59	37	48	67
Pb	37	37	51	28	32
Th	12	12	27	20	22
Modes (vol. %)					
Quartz	34·1	35·5	38·4	35·5	10·4
K-feldspar	26·1	30·8	35·8	27·0	7·5
Plagioclase	33·7	31·5	24·0	34·8	37·8
Biotite	4·2	1·4	1·7	tr	14·9
Hornblende	....	....	....	2·0	27·7
Rest	1·9	0·8	0·1	0·5	1·7
Plag. An%	29	19	13	18	34

Structure

Determination of the structure in the gneisses around the Mt Gardner Adamellite is difficult because of inadequate outcrop. Lithological banding and foliation in the gneiss appear to be mutually parallel. In isolated outcrops near the northern margin of the pluton these features strike roughly north-south and dip gently (20°-30°) west. This represents a marked local departure from the regional east-west strike in the south coast part of the Albany-Esperance Block. A weak mineral lineation, defined by preferred orientation of elongate biotite flakes, plunges southwest at about 15°-25°. This is assumed to be a *b*-lineation.

Mt Gardner Adamellite

Field occurrence and facies

The Mt Gardner Adamellite outcrops prominently over an area measuring 6½ x 3½ km, but the actual dimensions of the pluton may be greater because the margins are almost completely obscured by the Southern Ocean or by Recent aeolian sand. The pluton is topographically expressed as a group of dome-shaped hills which rise steeply from the sea to a maximum elevation of 400 m at Mt Gardner. Two main facies have been recognised:

(i) Porphyritic adamellite

(ii) Microadamellite.

Porphyritic adamellite constitutes the bulk of the pluton. It is a fairly homogeneous, massive rock with abundant megacrysts of K-feldspar up to 4 x 4 x 2 cm in size set in a medium-grained allotriomorphic to hypidiomorphic granular groundmass.

Microadamellite occurs as minor dykes up to a few metres wide within the porphyritic adamellite. It typically shows fine-grained, allotriomorphic granular texture, but the local presence of anhedral megacrysts of K-feldspar up to 2 x 2 x 1 cm in size produces a seriate texture in places.

Mineralogy

Both facies of the Mt Gardner Adamellite are composed mainly of K-feldspar, plagioclase, and quartz in order of decreasing abundance, with biotite the main accessory. Minor accessories include magnetite, sphene, muscovite, metamict, allanite, epidote, and zircon. Chemical analyses, mesonorms and modes of representative samples are presented in Table 2.

The K-feldspar is microcline, occurring as anhedral megacrysts and in the groundmass. Larger grains show a strong tendency to corrode and enclose the other minerals, and some megacrysts are strongly poikilitic. Crosshatching may be well developed, rudimentary, or absent, and Carlsbad twinning is common. Perthitic texture is usually conspicuous, with film, string, and patch types most common. The plagioclase is anhedral to subhedral, albite-twinned oligoclase-andesine (An_{28}-An_{31}), commonly with albite rims on grain boundaries in contact with K-feldspar. Patchy alteration to saussurite or sericite is not unusual. Quartz is anhedral and commonly shows undulose extinction. Biotite is anhedral to subhedral with X = light brown, Y = Z = dark brown. In the porphyritic facies it tends to be concentrated with the minor accessories in wispy aggregates, whereas in the microadamellite it occurs as disseminated flakes commonly showing a preferred orientation. Alteration to chlorite is evident in some samples.

Textures and crystallisation history

The crystallisation history of the Mt Gardner Adamellite is not easily determined from grain relations. Apatite and zircon may be included in magnetite and sphene, and all these minerals tend to be euhedral against, and enclosed by, biotite. Biotite and quartz are occasionally enclosed by plagioclase, and these three minerals (especially plagioclase) are commonly corroded and enclosed by K-feldspar. Plagioclase is locally euhedral against quartz, and quartz is commonly interstitial to both feldspars. Hence the order in which the minerals commenced to crystallise appears to be: (i) apatite and zircon;

Table 2

Chemical analyses, mesonorms, and modes of the porphyritic adamellite and microadamellite facies of the Mt Gardner Adamellite

	Porphyritic Adamellite			Microadamellite		
	56582	65625	65629	65626	65628	65630
SiO_2	66·07	67·74	67·89	69·42	68·88	71·43
Al_2O_3	16·25	16·18	15·20	15·07	14·87	14·33
Fe_2O_3	2·25	1·42	1·73	1·51	1·52	1·88
FeO	1·43	1·14	1·31	1·52	1·63	1·11
MgO	0·90	0·53	0·81	0·71	1·00	0·62
CaO	2·68	2·25	1·99	2·14	2·11	1·22
Na_2O	3·71	3·50	3·14	3·29	3·14	2·85
K_2O	5·49	6·00	6·43	5·25	5·56	5·83
H_2O^+	0·54	0·38	0·47	0·80	0·87	0·62
H_2O^-	0·08	0·10	0·13	0·09	0·11	0·18
TiO_2	0·64	0·38	0·54	0·49	0·52	0·43
P_2O_5	0·24	0·20	0·19	0·13	0·18	0·11
MnO	0·06	0·05	0·06	0·05	0·05	0·03
Total	100·34	99·87	99·89	100·47	100·44	100·64
	Mesonorms (mol. %)					
Q	17·63	19·10	20·35	24·70	24·17	28·75
Or	29·93	33·85	35·87	28·61	29·68	33·11
Ab	33·52	31·71	28·58	29·92	28·59	25·98
An	9·59	8·64	6·87	8·19	7·58	3·93
C	0·79	0·89	0·65	1·12	1·04	2·13
Bi	4·31	3·10	4·27	4·53	5·83	2·94
Mt	2·36	1·49	1·83	1·59	1·60	1·99
Sp	1·34	0·79	1·14	1·02	1·09	0·90
Ap	0·50	0·42	0·40	0·27	0·38	0·23
	Trace Elements (p.p.m.)					
Li	19	13	21	17	19	16
Co	7	4	5	3	4	6
Ni	33	33	19	33	18	19
Cu	6	8	5	6	9	5
Zn	79	68	70	70	68	65
Rb	187	211	222	208	196	221
Sr	754	641	606	533	469	218
Y	56	49	66	18	77	18
Zr	456	336	409	353	490	364
Ba	3789	3818	3962	2747	2949	1448
La	179	115	106	182	191	136
Pb	44	48	49	45	41	38
Th	23	18	25	39	39	52
	Modes (vol. %)					
Quartz	19·1	19·6	19·7	23·0	23·6	27·4
K-feldspar	39·5	43·6	44·8	36·9	39·1	41·2
Plagioclase	34·7	28·9	28·9	31·2	30·6	24·4
Biotite	4·2	5·1	4·1	6·8	5·4	5·5
Rest	2·5	2·8	2·5	2·1	1·3	1·5
Plag. An%	28–30	28–30	28	28	31	29–30

(ii) magnetite and sphene; (iii) biotite; (iv) plagioclase; (v) K-feldspar. The position of quartz in the crystallisation sequence is regarded as doubtful. There was probably a large overlap between the crystallisation ranges of the felsic minerals.

Several textural features of the Mt Gardner Adamellite give rise to speculation regarding certain aspects of the petrogenesis of the pluton. The tendency for biotite and minor accessory minerals to occur in aggregates suggests that these minerals may be refractory remants of parent rock or xenoliths rather than products of magmatic crystallisation. The preferred orientation of disseminated biotite flakes in the microadamellite parallel to intrusion margins is probably a primary flow structure. The strong tendency of K-feldspar to corrode, enclose, and replace the other minerals suggests a post-magmatic (autometasomatic) phase of K-feldspar growth. Perthite and albite rims on plagioclase are believed to have developed by subsolidus reorganisation of albite exsolved from K-feldspar (see Phillips 1964). The common occurrence of undulose extinction in quartz and K-feldspar, and occasional fractured feldspar grains and bent biotite flakes suggest some post-consolidation deformation of the pluton.

Chemical analyses

A comparison of the analyses in Table 2 shows that the porphyritic adamellite and microadamellite facies of the Mt Gardner Adamellite are very similar in composition. The microadamellite tends to be slightly richer in SiO_2 and Th, and slightly poorer in Al_2O_3, P_2O_5, Sr, and Ba than the porphyritic adamellite.

Minor intrusions

Both major facies of the Mt Gardner Adamellite are cut by occasional small veins of pegmatite and quartz a few centimetres in width. The relative ages of the pegmatite and quartz veins are not known.

The pegmatite is a coarse-grained, hypidiomorphic-textured rock composed mainly of quartz, oligoclase, and microcline, with minor magnetite and biotite. The quartz veins are coarse-grained, allotriomorphic-textured, and composed almost entirely of quartz.

Xenoliths

Xenoliths are fairly common in the porphyritic adamellite. They occur as clearly defined, angular blocks up to about 20 m across, showing little evidence of assimilation. The lithologies represented are restricted to those found in the nearby country rocks, with xenoliths of granitic gneiss outnumbering those of dioritic gneiss by at least ten to one. Chemical analyses and modes of representative samples are presented in Table 3 for comparison with the analytical data for the country rock gneisses listed in Table 1. The xenoliths generally show random orientation of their internal foliation, and therefore appear to have been rotated during their incorporation in the pluton.

The microadamellite dykes contain few xenoliths, mostly of porphyritic adamellite.

It is concluded that the xenoliths in the Mt Gardner Adamellite have been rafted from the adjacent wall and roof rocks. Their nature is consistent with intrusive magmatic emplacement of the pluton, rather than metasomatic emplacement, but there is no evidence to suggest that they have been transported from significantly greater depth.

Contact relations

Contacts between the Mt Gardner Adamellite and surrounding gneisses are mostly obscured, either by the Southern Ocean or by superficial deposits. The sole exception occurs at the north-

Table 3

Chemical analyses and modes of granitic and dioritic gneiss xenoliths in the Mt Gardner Adamellite

	Granitic gneiss		Dioritic gneiss
	56583	65631	65627
SiO_2	71·45	78·91	56·19
Al_2O_3	13·66	10·79	13·44
Fe_2O_3	1·57	1·16	1·87
FeO	1·24	0·50	5·05
MgO	0·42	0·15	7·55
CaO	1·24	0·49	5·93
Na_2O	2·86	1·98	2·37
K_2O	5·90	6·01	4·60
H_2O^+	0·57	0·28	0·95
H_2O^-	0·13	0·13	0·10
TiO_2	0·33	0·07	1·05
P_2O_5	0·08	0·02	0·72
MnO	0·04	....	0·14
Total	99·49	100·49	99·96
Trace Elements (p.p.m.)			
Li	14	2	35
Co	5	<3	37
Ni	31	15	204
Cu	6	5	7
Zn	61	27	113
Rb	238	191	188
Sr	249	219	1136
Y	25	8	29
Zr	297	88	216
Ba	1454	1330	3913
La	316	<6	84
Pb	51	34	33
Th	78	<5	16
Modes (vol. %)			
Quartz	27·3	43·7	13·4
K-feldspar	35·6	40·7	14·9
Plagioclase	31·2	14·2	23·5
Biotite	4·0	0·4	21·7
Hornblende	....	....	25·0
Rest	1·9	1·0	1·5
Plag. An %	28	20	31

ern margin where about 600 m of the contact is exposed at Point Valiant. Here the contacts are sharp in detail, but the pluton margin is somewhat indefinite, being defined by a wide zone in which gneiss and adamellite are intermingled. Porphyritic adamellite is interbanded with the gneiss in lit-par-lit fashion on a large scale, and irregular discordant intrusions of porphyritic adamellite and microadamellite into gneiss are common. Small veins of quartz and pegmatite are also fairly numerous. The gneiss in this contact zone locally shows development of K-feldspar porphyroblasts, suggesting K-metasomatism, but there is no evidence of major thermal effects in the contact rocks, nor is there any sign of marginal chilling in the adamellite.

It is concluded that the contact relations are consistent with intrusive magmatic emplacement of the Mt Gardner Adamellite, rather than metasomatic emplacement.

Discussion

Petrogensis of the Mt Gardner Adamellite

Contact relations and the nature of xenoliths strongly suggest that the Mt Gardner Adamellite was intrusively emplaced as a magma or crystal mush. The spatial association and similarity in composition between the porphyritic adamellite and microadamellite facies suggest a close genetic relationship between them. The nature of this relationship is investigated below.

Despite the strong similarity in bulk chemical composition it is evident in Table 4 that K/Rb, Ba/K, Ba/Rb, and Sr/Ca ratios are slightly lower in the microadamellite than the porphyritic adamellite. Consideration of the substitution behaviour of Ba and Rb for K, and of Sr for Ca during progressive fractional crystallisation of granitic magma (Taylor 1965) suggests that these results are consistent with the microadamellite dykes being the residual product of fractional crystallisation of the porphyritic adamellite magma. The pegmatite and quartz veins are possibly the product of more advanced fractionation.

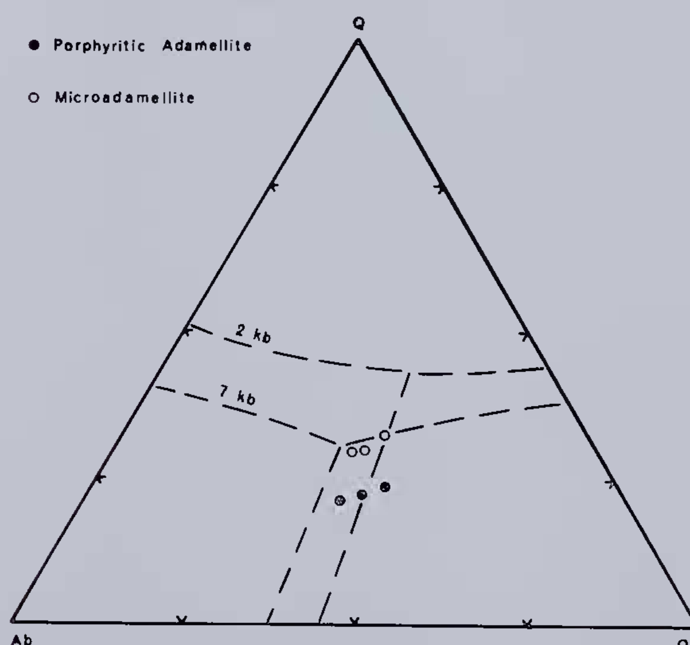

Figure 3.—Mesonormative Ab-Or-Q proportions for the Mt Gardner Adamellite samples compared with the cotectic lines for the system An-Ab-Or-Q-H_2O where Ab/An = 3.8, for water vapour pressures of 2 kb (from von Platen 1965) and 7 kb (inferred from von Platen 1965, and von Platen and Höller 1966).

In Figure 3 (after von Platen 1965, and von Platen and Höller 1966) the Mt Gardner Adamellite samples are compared with phase relations in the system An-Ab-Or-Q-H_2O for the appropriate Ab/An ratio of 3.8. The microadamellite samples approximate the minimum melting composition for water vapour pressures around 7kb, whereas the porphyritic adamellite samples plot significantly further from the Q-corner. Consideration of the crystallisation behaviour of melts in the system An-Ab-Or-Q-H_2O (see von Platen 1965) shows that these results support the contention that the microadamellite dykes are the residual product of fractional crystallisation of the porphyritic adamellite magma, and suggests that fractionation occurred at a water vapour pressure of 7 kb or less.

Filter pressing resulting from tectonic disturbance of the pluton during the later stages of crystallisation is seen as a likely factionation mechanism.

Origin of the magma

Stephenson (1973 in prep.) has argued that similar granitic plutons nearby are the product of anatexis of crustal rocks during the orogeny responsible for the high-grade metamorphism of the country rocks. A similar origin for the Mt Gardner Adamellite magma seems likely, although there are no radiometric or Sr isoptope data available to confirm or refute this suggestion.

The country rocks in the vicinity of the Mt Gardner Adamellite belong to the amphibolite facies, and hence may have attained a temperature high enough to cause substantial anatexis. Furthermore, the country rocks are composed mainly of granitic gneiss and therefore could yield large amounts of granitic magma on partial melting. Thus it is possible that the Mt Gardner Adamellite may be the product of anatexis more or less *in situ*. However, this possibility can be ruled out on chemical grounds. It is reasonable to assume that elements concentrated in the final stages of fractional crystallisation of magma should also be concentrated in early-formed anatectic melts. Hence a magma formed by partial melting should show lower K/Rb, Ba/K, Ba/Rb, and Sr/Ca ratios than the parent rock (see Taylor 1965). Comparison of these ratios for the Mt Gardner Adamellite with those for the granitic and dioritic gneiss country rocks (Table 4) suggests that the pluton cannot have been formed *in situ* by partial or complete melting of the country rocks. Therefore an origin at greater depth is assumed.

Table 4

Element ratios for the Mt Gardner Adamellite and the gneissic country rocks

	K/Rb	Ba/K $\times 10^3$	Ba/Rb	Sr/Ca $\times 10^3$
Porphyritic Adamellite				
56582	294	83	20	39
65625	284	77	18	40
65629	290	74	18	43
Microadamellite				
65626	252	63	13	35
65628	284	64	15	31
65630	264	30	6·6	25
Granitic Gneiss				
56578	196	56	11	17
56585	208	32	6·6	12
56592	163	6·4	1·0	5·7
56593	242	49	12	12
Dioritic Gneiss				
54513	154	61	9·4	13

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